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THESIS

CALIBRATION OF THE NAVAL POSTGRADUATE SCHOOL 3.5' X 5.0' ACADEMIC WIND TUNNEL

by

Duane E. Nestor

September, 1990

Thesis Advisor: Louis V. Schmidt

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CALIBRATION OF THE NAVAL POSTGRADUATE
SCHOOL 3.5' X 5.0' ACADEMIC
WIND TUNNEL

by

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B.S., United States Naval Academy, 1983
M.S., Naval Postgraduate School, 1990

Submitted in partial fulfillment
of the requirements for the degree of

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G.E. Schacher
Dean of Faculty and Graduate Studies

ABSTRACT

The purpose of this thesis was to revitalize the Naval Postgraduate School's 3.5' x 5.0' academic wind tunnel. The wind tunnel had sustained previous damage to one of two sets of counter-rotating blades. The damage forced the operation of the tunnel on one set of blades. Because of this change in configuration a wind tunnel calibration was deemed necessary. Along with the calibration a digital data acquisition system was designed and implemented to aid in the data collection, storage and analysis for this project and future projects utilizing this wind tunnel. The test section airspeed calibration data contained a substantial amount of scatter indicating flow straighteners may be required. The wind tunnel turbulence intensity was found to be relatively low considering the configuration change and is expected to reach an acceptable level (less than 0.3 percent) with the planned installation of turbulence screens in the settling chamber.

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I. INTRODUCTION

A. BACKGROUND

The goal in any experiment is to accurately model the event to be analyzed and then to analyze the event without introducing bias. In the case of a wind tunnel it is desired to simulate the flow of air over a body as it would occur in flight. During the design of the wind tunnel great care is taken to ensure undisturbed, uniform flow through the test section. Even so, there will exist some disturbances that must be either accounted for in the data or determined to be insignificant.

The subject wind tunnel was designed with two counter-rotating sets of blades. The second set of blades was incorporated to remove the swirl introduced by the first set as well as to provide a tunnel test section dynamic pressure of approximately 80 lbs/ft^2. In addition, turning vanes at each corner of the circuit help sustain straight flow. The set of turning vanes just upstream of the settling chamber have trailing edge tabs which may be deflected to remove the flow swirl in the test section.

The wind tunnel is currently only able to utilize one set of blades. This change in the operating characteristics of the wind tunnel motivated the

re-examination of the flow quality. The variables used to quantify the wind tunnel's flow quality are [Ref. 1]:

- Test section airspeed
- Lateral velocity variation
- Flow angularity
- Longitudinal pressure gradient
- Turbulence level

1. Test Section Airspeed

The last airspeed calibration was performed in June, 1980 with both sets of fan blades operational. The airspeed calibration should be completed every two years in order to preserve standards of flow quality.

2. Lateral Velocity Variation

The lateral velocity variation can be measured by a lateral traverse of a pitot-static probe in the test section. A uniform velocity profile is desired.

3. Flow Angularity

The presence of swirl in the test section can be detected by measuring the flow angularity. A five tube yaw head is available to measure flow inclination both vertically and laterally to an accuracy of $\pm$ 0.03 degrees. A lateral traverse of the yaw head in the test section will provide flow inclination information across

the test section. This information, in conjunction with the capability to adjust the tabs on the turning vanes, makes possible flow adjustments to remove swirl in the test section.

4. Longitudinal Pressure Gradient

A check of the longitudinal pressure gradient will determine if there is flow leakage in the test section doors. The information obtained also makes possible an estimation of buoyancy corrections to be applied to the model drag coefficient.

5. Turbulence Level

The turbulence level is measured using a hot-wire anemometer or a laser doppler velocimeter. In this project the hot-wire was used because of its simplicity. The flow turbulence level is generally considered acceptable when it is less than 0.003.

B. DATA ACQUISITION

The product of an experiment is some set of data. It is desired to acquire, manipulate and store this data for future reference. In the past the collection of data consisted of a person reading the data off of an instrument and recording it on paper. The manipulation was done with a calculator or computer for which the

data had to be entered. Finally the data could be displayed in some manner for analysis. This process was time consuming and subject to error at each step.

Today this task can be performed by a personal computer at relatively low cost. The analog information supplied by the sensors can be filtered and then converted to digital form. The digital information may be manipulated, displayed or stored in a very efficient manner. The data can also be transported on disk or by phone line and used by another computer for further manipulation without the requirement of data entry. Once in digital form the likelihood of an error being made is remote. The experimenter is free of the monotonous task of data collection and manipulation and is able to use his time to analyze the data.

An additional advantage of the personal computer is its ability to accurately control experiments. A digital signal, developed within the computer, may be converted to an analog signal to control a device. The accuracy of the internal clock of the computer enables control to be provided much more accurately than possible through human means. The ability of the computer to coordinate control and acquisition greatly reduces the time required to run an experiment.

C. THESIS GOALS

The purpose of this study was to re-establish a functional operating system to:

- Measure pressure signals using a Scanivalve®

- Control the pitch angle drive mechanism on the existing three component balance
- Analyze the flow quality parameters
- Integrate the sensors with a signal conditioning and data acquisition system

The final objective was to obtain a high quality flow in the test section. Where required, the information obtained in this study would be used to make recommendations on measures to increase the flow quality in the test section.

II. HARDWARE

A. WIND TUNNEL

The subject wind tunnel is located in Halligan Hall of the Naval Postgraduate School, Monterey, CA. The tunnel (see Figure 1) is of the closed-circuit type utilizing two 150 HP electric motors to power two, four blade, counter-rotating propellers. During this experiment the upper set of blades were removed from the tunnel. This limited the tunnel velocity to approximately 160 kts and eliminated the designed method for reduction of swirl. The removal was required due to previous damage to the blades. The tunnel uses turning vanes at each corner of the circuit as well as contraction to smooth the flow through the corners. The ratio of the settling chamber area to the test section area (known as contraction ratio) is 6.9. A breather slot is located at the downstream end of the test section to maintain a uniform pressure in the test section relative to atmospheric pressure. The test section is slightly divergent in cross-sectional area to provide compensation to the flow to account for boundary layer growth.

The reference dynamic pressure for the tunnel is determined at the inlet to the test section. The total pressure is obtained from a Kiel probe while the reference

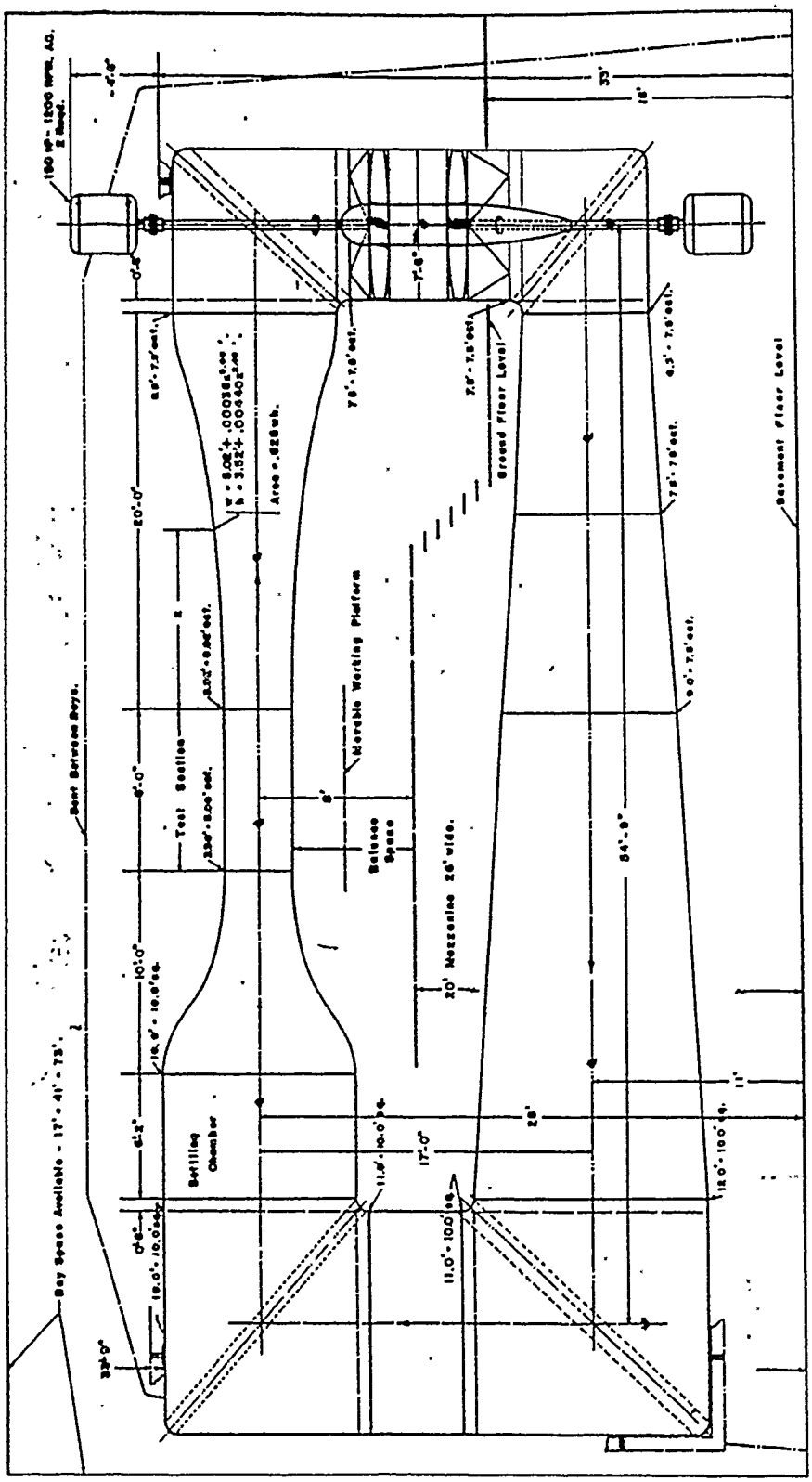

Figure 1. Academic Wind Tunnel

static pressure is sensed by a ring of flush, wall mounted static ports. The use of multiple static ports results in an averaging of the static pressure to minimize the effect of small pressure disturbances or asymmetries. The reference pressure is read in centimeters of H_2O on a manometer.

The wind tunnel has available a three component balance installed beneath the test section on an isolated support base. The balance provides the capability to measure lift, drag and pitching moment at a focal point in the neighborhood of the tunnel centerline. This metric system has a remote pitch angle drive mechanism which may be used to alter angle of attack on a test model installed either on a three strut or plate support system. The calibration of the balance was not a goal of this thesis; however, upon completion of the wind tunnel flow quality analysis this calibration should be completed. The procedures for the last calibration of the balance are given in Reference 2.

The irreversible worm gear drive on the pitch drive mechanism is belt driven by a DC motor. The DC motor is controlled by either a manual control box or externally through a set of relays. The manual control box has a rheostat for control of the speed of the angle drive motor. This parameter can not be controlled externally; however, the rheostat on the control box is not disabled while controlling the motor through the relays.

B. COMPUTER

An IBM Personal System/2™ Model 50 was used to acquire, process and display data for the calibrations completed. The computer was equipped with an 80287 math co-processor chip to decrease the processing time of the data. A National Instruments MC-MIO-16 input/output board was used to interface the computer with the external circuitry. The interface pinout code is shown in Figure 2.

The MC-MIO-16 provides sixteen single-ended analog input channels (pins 3 through 18). For increased accuracy, differential input was used. This reduced the available number of channels to eight (adjacent pins are paired with the odd numbered pin being the positive input pin). If more channels are required the sources can be multiplexed to provide for up to 256 single-ended inputs. The voltage range for the analog signals was set on the MC-MIO-16 to ± 10 volts. The MC-MIO-16 is capable of sampling analog signals at a maximum rate of 91,000 per second. The analog to digital conversion is performed using twelve bits which provides a voltage resolution of ± 2.44 mV. Two analog output channels are provided (pins 20 and 21) and were also set to ± 10 volts. Eight digital input/output channels are also available (pins 25 through 32). [Ref. 3]

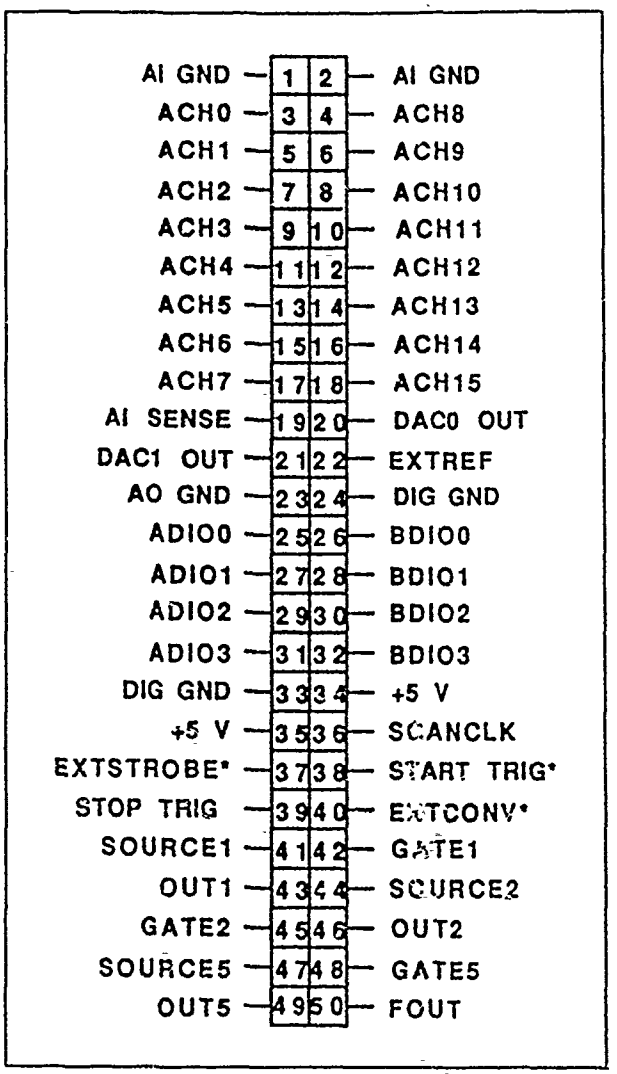
AI GND 1 2 AI GND
ACH0 3 4 ACH8
ACH1 5 6 ACH9
ACH2 7 8 ACH10
ACH3 9 10 ACH11
ACH4 11 12 ACH12
ACH5 13 14 ACH13
ACH6 15 16 ACH14
ACH7 17 18 ACH15
AI SENSE 19 20 DAC0 OUT
DAC1 OUT 21 22 EXTREF
AO GND 23 24 DIG GND
ADIO0 25 26 BDIO0
ADIO1 27 28 BDIO1
ADIO2 29 30 BDIO2
ADIO3 31 32 BDIO3
DIG GND 33 34 +5 V
+5 V 35 36 SCANCLK
EXTSTROBE* 37 38 START TRIG*
STOP TRIG 39 40 EXTCONV*
SOURCE1 41 42 GATE1
OUT1 43 44 SOURCE2
GATE2 45 46 OUT2
SOURCE5 47 48 GATE5
OUT5 49 50 FOUT

Figure 2. I/O Interface

C. SCANIVALVE®

A 48 port Scanivalve® was used to convert the pressure signals to an analog voltage. The 48 ports can be selected individually to provide any of 48 pressures to a single pressure transducer which corresponds to an analog multiplexer. The requirement for only one pressure transducer reduces the number of calibrations needed to one. It also reduces the cost of the experimental set up if a large number

of pressure signals are required. A Pacific Model 8256 amplifier was also available to condition the signal from the pressure transducer prior to the analog to digital conversion.

The Scanivalve® was connected to a [illegible]roller which triggered the port change mechanism in the Scanivalve®. [illegible] minals, located on a terminal strip on the back side of the controller, enabled external computer control. The current port position is supplied by seven digital lines from the Scanivalve®. The control of the Scanivalve® will be discussed in Chapter IV.

D. HOT-WIRE ANEMOMETRY

A 0.0001 inch diameter, tungsten hot-wire supported between the tips of two steel needles on a probe designed by Professor James Miller of the Naval Postgraduate School was used as the velocity perturbation sensor. Internal circuitry provides linearization on voltage versus velocity. By normalizing the steady output voltage to 1.0 VDC, the unsteady voltage signal will provide a direct measure of the turbulence level in a moving airstream. The unsteady output voltage could either be measured by a true RMS voltmeter or digitized by the data acquisition system for subsequent analysis. This system is shown in Figure 3.

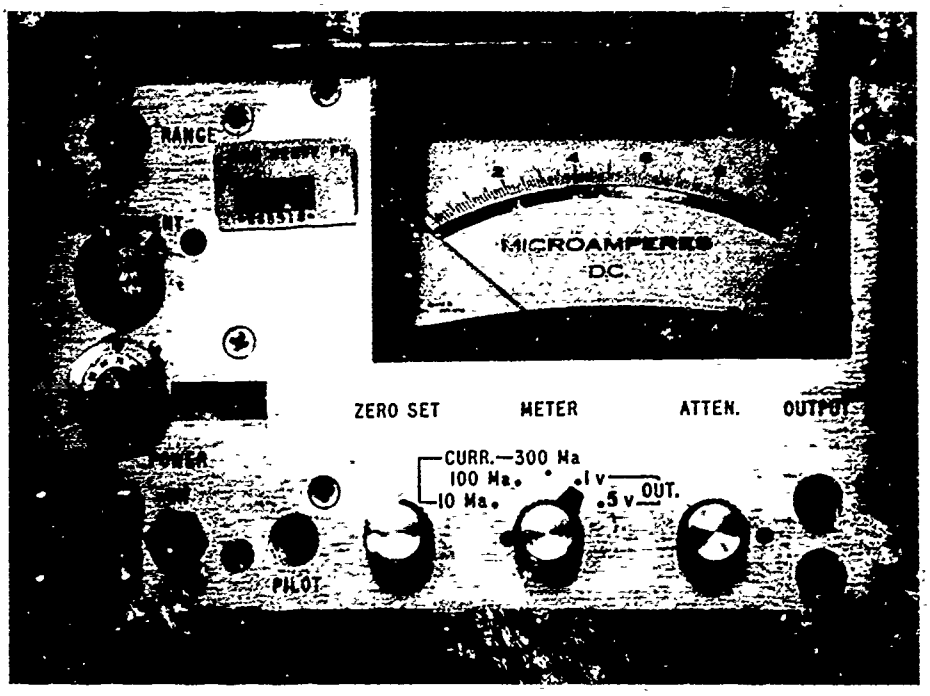

Figure 3. Linearized Hot-wire Anemometer

III. WIND TUNNEL CALIBRATION

Of the calibration requirements listed in Chapter I only the airspeed and turbulence calibrations were performed. At the completion of these measurements it was determined that the flow quality could be improved by wind tunnel modifications. In light of this only the procedures for those measurements completed are given below.

A. TEST SECTION AIRSPEED CALIBRATION

The test section dynamic pressure in the region of the tunnel centerline may be directly calibrated by using a pitot-static probe installed in the test section (see Fig. 4) and concurrently measuring companion readings of pressure differences on the upstream reference sources. After the calibration is completed, the upstream reference sources may be used when establishing the dynamic pressure in the test section without the presence of this pitot-static probe. This allows the establishment of dynamic pressures about a test model or other sensors such as a yaw head in the test section.

The upstream reference sources consist of a shrouded total head (Kiel) probe mounted three inches ahead of the test section leading edge in conjunction with static pressures provided by a ring of five flush, wall mounted static ports

collocated with the Kiel probe. A compressibility correction was provided to the difference between total and static pressures as measured by the pitot-static probe. From the isentropic, perfect gas relations for compressible flow the ratio of the total pressure to the static pressure is given as [Ref. 4]:

$$\frac{P_t}{P_s} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

Multiplying both sides by the static pressure (P_s) and then subtracting the static pressure from both sides gives:

$$P_t - P_s = P_s\left[\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}-1\right] \qquad (3.1)$$

From the definition of dynamic pressure:

$$q = \frac{1}{2}\rho V^2$$

From the perfect gas assumption:

$$\rho = \frac{P_s}{RT}$$

Combining the last two equations gives:

$$q = \frac{P_s V^2}{2RT} \qquad (3.2)$$

Using the expression for the speed of sound:

$$a^2 = \gamma RT$$

Equation (3.2) becomes:

$$q = \frac{\gamma}{2} P_s M^2$$

Substituting this expression into equation (3.1):

$$P_t - P_s = \frac{2q}{\gamma M^2}\left[\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}-1\right] \qquad (3.3)$$

Equation (3.3) can be simplified by expressing the term in parenthesis as a binomial series. A binomial series has the form [Ref. 5]:

$$(1+x)^s = 1+sx+\frac{s(s-1)(s-2)}{2!}x^2+\frac{s(s-1)(s-2)}{3!}x^3+\ldots$$

After the binomial expansion equation (3.3) becomes:

$$P_t - P_s = q\left(1+\frac{M^2}{4}+\frac{(2-\gamma)M^4}{24}+\ldots\right)$$

For $\gamma = 1.4$:

$$q = \frac{(P_t - P_s)}{\left(1+\frac{M^2}{4}+\frac{M^4}{40}+\ldots\right)} \qquad (3.4)$$

Equation (3.4) was used in this calibration to correct the measured test section pressure difference for the slight compressibility effect to obtain the test section

dynamic pressure. This correction was included in the calibration curve and so the tunnel test section dynamic pressure can be obtained by measuring the reference ΔP.

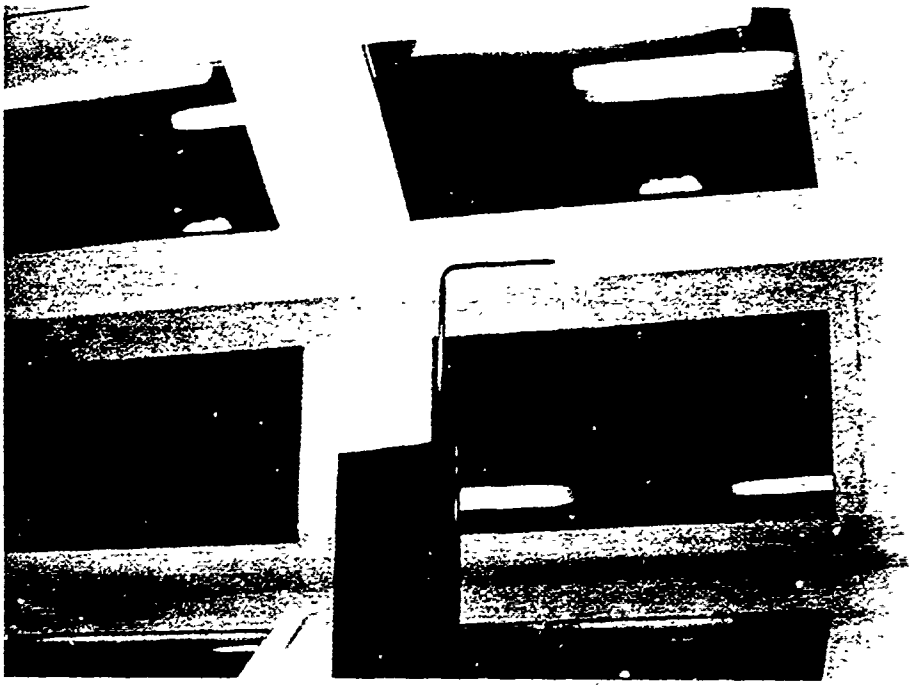

Figure 4. Velocity Calibration Set-up

B. TURBULENCE INTENSITY DETERMINATION

The turbulence intensity is a measure of the fluctuations in the flow. The velocity of the flow can be broken up into an average term and a fluctuation term. When the coordinate system for tunnel velocity is aligned with the tunnel test section centerline, then:

$$u = \bar{u} + u'$$
$$v = \bar{v} + v', \quad \bar{v} = 0$$
$$w = \bar{w} + w', \quad \bar{w} = 0$$

The fluctuations of velocity vary with time and so the primed terms in the equations above can not be used directly as a measure of the turbulence intensity (see Fig. 5).

For this calibration the root mean square of the fluctuations was used as the measure of the turbulence intensity. In the discrete form:

$$u'_{rms} = \left[\frac{1}{N}\sum_{n=1}^{N} u'^2\right]^{\frac{1}{2}}$$

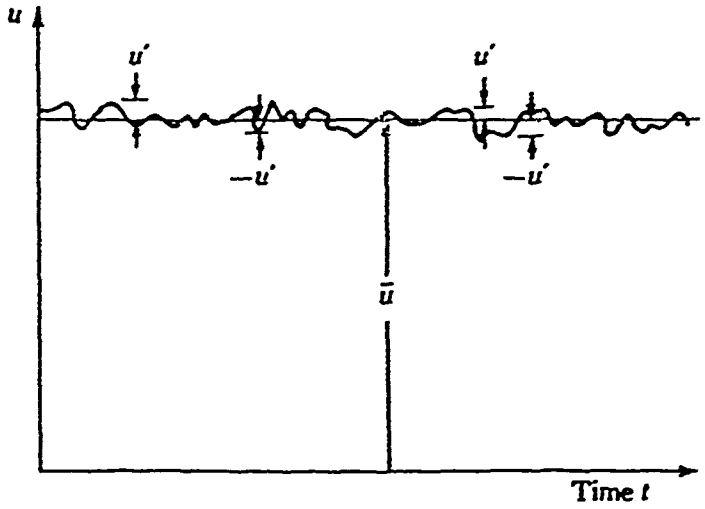

Figure 5. Turbulence Fluctuations [Ref. 6]

To obtain the turbulence level the root mean square term is normalized with the freestream velocity giving:

$$Turb = \frac{u'_{rms}}{\bar{u}}$$

The turbulence intensity can be obtained for velocity fluctuations in any of the three axial directions.

One goal of this thesis was to determine the level of the turbulence intensity in the wind tunnel. To accomplish this the average velocities and fluctuations shown in the equations previously were measured. The measurement of the fluctuations requires a large bandwidth velocity sensing system (e.g., f = 0 to 10000 Hz.). A hot-wire anemometry system was selected for measuring turbulence in contrast to other approaches (e.g., laser doppler velocimeter) because of the simplicity of test operation. The hot-wire was installed near the test section centerline (see Fig. 6) with the probe aligned parallel to the centerline.

In this orientation a single hot-wire is not able to discern between the vertical and axial velocity components. Because of this, the axial and vertical components are included in the following development by introducing a new variable:

$$\vec{V} = u\hat{i} + w\hat{k}$$

The hot-wire was found to be sensitive to vertical motion. This point will be discussed in further detail in Chapter VI.

Hot-wire anemometry is based on the affect of the flow velocity on the heat transfer rate of a thin tungsten wire stretched between two probes. According to

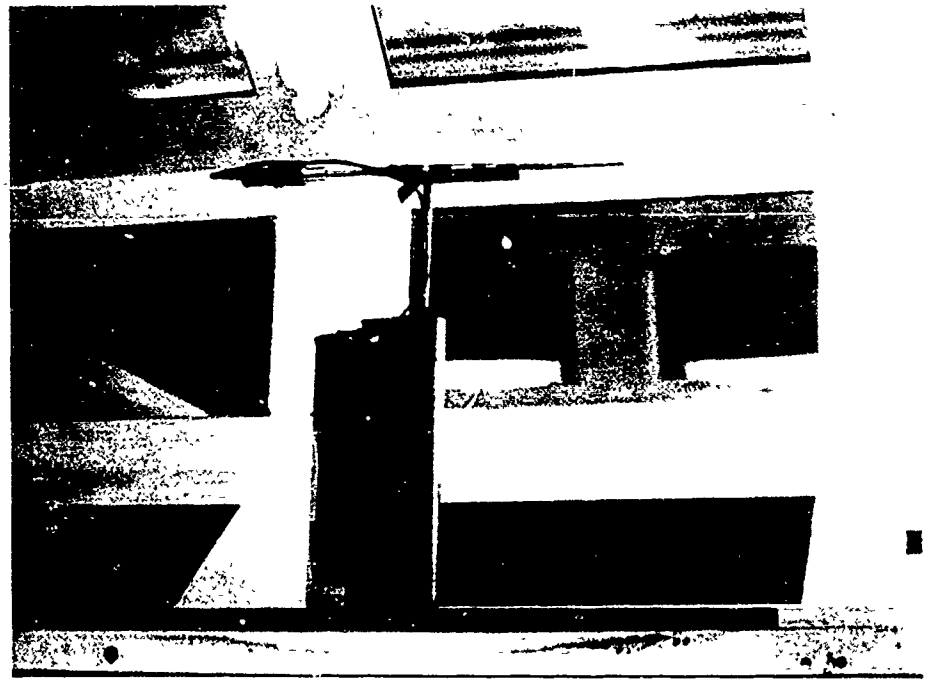

Figure 6. Hot-wire Installation

King's Law the plot of the voltage output of a standard hot-wire system versus velocity is nonlinear. This curve was linearized by the internal circuitry of the hot-wire system used for this project. With this system a given voltage change corresponds to the same velocity change regardless of the mean velocity. The equation for a change in velocity becomes:

$$|\Delta \vec{V}| = a\Delta E \qquad (3.5)$$

where a is constant.

From the definition of the root mean square:

$$|\vec{V}|_{rms} = \left[\frac{1}{N}\sum_{n=0}^{N}|\Delta\vec{V}|^2\right]^{\frac{1}{2}}$$

Substituting Equation (3.5):

$$|\vec{V}|_{rms} = \left[\frac{1}{N}\sum_{n=0}^{N} a^2(\Delta E)^2\right]^{\frac{1}{2}}$$

or:

$$|\vec{V}|_{rms} = a\left[\frac{1}{N}\sum_{n=0}^{N}(\Delta E)^2\right]^{\frac{1}{2}}$$

If u_{rms} is normalized with the mean velocity as discussed earlier then:

$$TURB = \frac{|\vec{V}|_{rms}}{\overline{V}} = \frac{a\left[\frac{1}{N}\sum_{n=0}^{N}(\Delta E)^2\right]^{\frac{1}{2}}}{a\overline{E}}$$

or:

$$TURB = \frac{|\vec{V}|_{rms}}{\overline{V}} = \frac{E_{rms}}{\overline{E}}$$

Thus the turbulence intensity can be measured directly from the voltage output.

The frequency domain of the turbulent measurements can also provide important information. To completely reconstruct the continuous signal through discrete sampling the Nyquist criterion requires a sampling rate of twice the highest frequency present. A plot of the frequency spectrum aids in determining whether

this criterion has been met. This plot can also reveal at what frequencies any turbulence reduction techniques should be directed. Finally the analysis in the frequency domain will indicate if signals are present that are not characteristic of wind tunnel turbulence. The presence of such signals could be caused by the measurement apparatus or other system dynamics with a resultant bias to the turbulence intensity measurement.

In order to obtain the required frequency spectrum information a Fourier Transform must be performed on the sampled data. The following derivation is given to provide a basic understanding of the Fast Fourier Transform concept in accordance with derivations in Ref. 7.

To determine the frequency output of the signal, the signal is represented by a Fourier series. The Fourier series is a trigonometric series of the form:

$$x(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos\frac{2\pi nt}{P} + b_n \sin\frac{2\pi nt}{P} \qquad (3.6)$$

where P ≡ period of the signal. The goal of the process is to determine the value of the non-zero coefficients, a_n and b_n. In order to solve for complex coefficients, DeMoivre's theorem is applied to obtain:

$$\cos\theta = \frac{1}{2}(e^{j\theta} + e^{-j\theta})$$

$$\sin\theta = \frac{1}{2j}(e^{j\theta} - e^{-j\theta})$$

and substituted into Eq (3.6) giving:

$$\begin{aligned} x(t) &= \frac{a_0}{2}+\frac{1}{2}\sum_{k=1}^{\infty} a_k(e^{j\theta}+e^{-j\theta})+\frac{1}{j}b_k(e^{j\theta}-e^{-j\theta}) \\ &= \frac{a_0}{2}+\sum_{k=1}^{\infty}\frac{1}{2}(a_k-jb_k)\,e^{j\theta}+\frac{1}{2}(a_k+jb_k)\,e^{-j\theta} \\ &= \sum_{k=-\infty}^{\infty}\frac{1}{2}[a_{|k|}-jsign(k)\,b_{|k|}]\,e^{j\theta} \end{aligned}$$

where:

$$sign(k) = \begin{cases} +1 & k \geq 0 \\ -1 & k < 0 \end{cases}$$

The series now has complex coefficients of the form:

$$X(k) = \frac{1}{2}[a_{|k|}-jsign(k)\,b_{|k|}]$$

and the series can be written as:

$$x(t) = \sum_{k=-\infty}^{\infty} X(k)\,e^{\frac{j2\pi kt}{P}}$$

For the case of discrete sampling the coefficients can be obtained from:

$$X(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\,e^{\frac{-j2\pi kn}{N}} \qquad (3.7)$$

where x(n) is the sampled data [Ref. 7]. The frequency for a non-zero coefficient is given by f=k/P. Thus for a non zero coefficient, X(k), the Fourier Transform will result in a value at the frequency, f, allowing one to determine the frequency spectrum of a discrete sampled signal.

The Fast Fourier Transform is an algorithm to reduce the computations required to obtain the frequency spectrum that was originally developed by Cooley and Tukey (Ref. 8). The following development of the FFT algorithm is found in Ref. 7. Rewriting Eq. (3.7) in a slightly different form:

$$X(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\left(e^{\frac{-j2\pi}{N}}\right)^{kn} \qquad (3.8)$$

The number of samples (N) is restricted to a power of 2. With N as a power of 2, N/2 is an integer. Equation (3.8) can be written as:

$$\begin{aligned} X(k) &= \frac{1}{N}\sum_{n=0}^{\frac{N}{2}-1}\left[x(n)\,e^{\frac{-j2\pi kn}{N}} + x\left(n+\frac{N}{2}\right)e^{\frac{-j2\pi k(n+\frac{N}{2})}{N}}\right] \\ &= \frac{1}{N}\sum_{n=0}^{\frac{N}{2}-1}\left[x(n) + x\left(n+\frac{N}{2}\right)e^{\frac{-j2\pi kN}{2N}}\right]e^{\frac{-j2\pi kn}{N}} \end{aligned}$$

This is further simplified by observing that the exponential in the brackets:

$$e^{\frac{-j2\pi kN}{2N}} = e^{-j\pi k} = (-1)^k$$

By limiting the number of inputs to a power of two the series size has been reduced by a power of two. In addition to making the Fourier Transform faster this algorithm has made it possible to perform the computation on personal computers. Several commercial software packages offer the FFT algorithm. Mathwork's PC Matlab© was used for this project.

As mentioned the output of the FFT is a set of complex coefficients. The power spectral density is obtained by multiplying each of the coefficients by its complex conjugate and plotting the result against its frequency. This plot was used to analyze the frequency content of the turbulence signal.

For the case of the isotropic turbulence as is assumed for flow in wind tunnels the Dryden model can be applied to obtain a length scale of the turbulence. In the Dryden model the axial length scale (L_1) can be determined from [Ref. 9]:

$$L_1 = \frac{P_1(0)\,\pi\,u}{2R_{uu}(0)} \qquad (3.9)$$

where:

$P_1(0) \equiv$ power spectral density at $\omega = 0$

$R_{uu}(0) \equiv$ Auto-correlation at zero time lag, and

$R_{uu}(0) \equiv E(u^2)$, the mean square value.

The length scale represents an ideal distance within which velocity perturbations are correlated.

One final consideration in discrete sampling is the aliasing of the signal by sources outside the criteria of $f < f_s/2$. Limits on hardware make it impossible to sample at $f_s = \infty$ and signals above $f_s/2$ will alias the data obtained at $f < f_s/2$. This problem is eliminated by low-pass filtering the analog signal prior to sampling.

IV. COMPUTER - SENSOR INTEGRATION

External circuitry was required to make the sensor outputs compatible with the MC-MIO-16 board. It was also necessary to make the MC-MIO board output compatible with the various control functions of the sensors. A short discussion is provided to enable future users to adapt the system to their needs more easily.

A. ANGLE OF ATTACK DETERMINATION AND CONTROL

While not a direct requirement of the wind tunnel calibration, control of the angle of attack drive system was accomplished while waiting for equipment to begin the airspeed calibration. The goal of this endeavor was to achieve control with an accuracy of ± 0.01°.

The angle of attack is determined from the voltage output of a ten-turn potentiometer attached to the pitch angle drive motor. The MC-MIO-16 board is accurate to 2.44 mV in its present configuration. The limits of the angle of attack were arbitrarily chosen to be ± 20°. With these two limits in mind and with the desired accuracy of ± 0.01° it was determined that the potentiometer would need a source of -15 V in conjunction with an operational amplifier with a gain of approximately 2.5 (see Fig. 7). An offset was also introduced by the amplifier to maintain the signal within the ± 10 V limit of the MC-MIO-16. This circuitry

coupled with a method of calibrating to the desired accuracy met the objective of ± 0.01°.

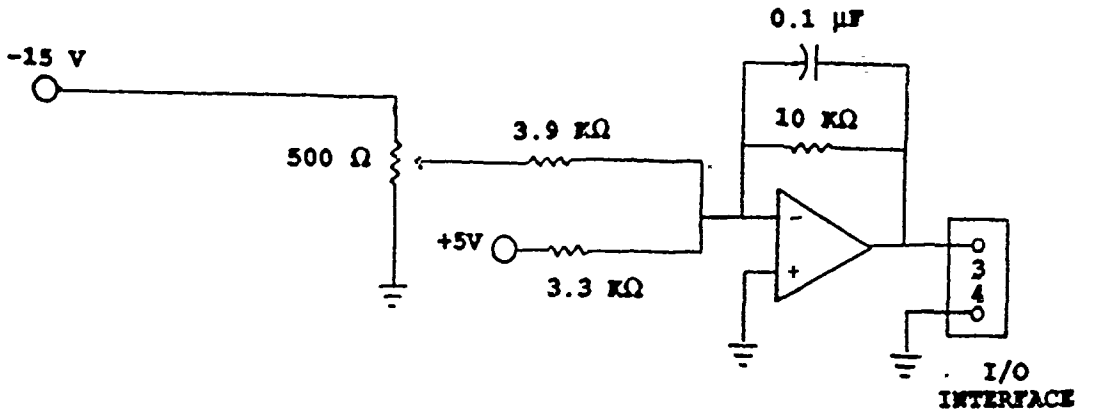

Figure 7. AOA Acquisition

Control of the angle of attack drive system is provided through two relays mounted beneath the test section on a wind tunnel support. Five volts obtained from the computer was used to close the appropriate relay (Fig. 8). As discussed in Chapter II the speed of the DC motor cannot be set externally. The speed must be set at or below 0.4 (control box value) to maintain the desired accuracy of ± 0.01°. At speeds above this setting the rotational inertia of the motor would carry the angle of attack past the desired value.

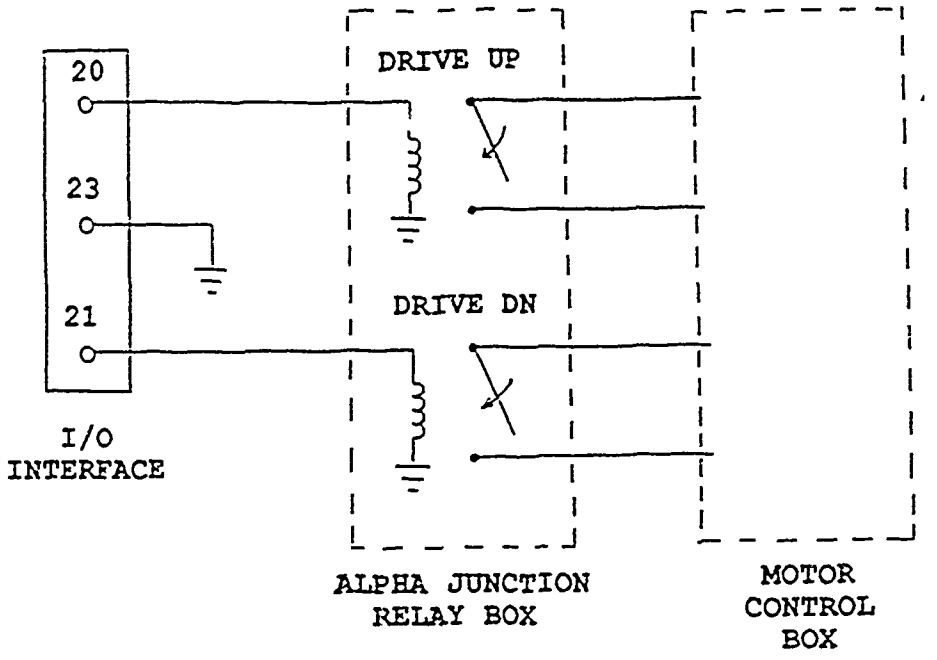

Figure 8. AOA Control

B. SCANIVALVE®

A 48 port Scanivalve® was used to obtain the pressure measurements. To utilize the Scanivalve® the computer must be able to determine what port the Scanivalve® is on, drive the Scanivalve® to a new port and finally determine the voltage output from the pressure transducer.

The Scanivalve® relays its port position through seven digital lines. The color coding for each line for this Scanivalve® and its corresponding base ten value are given in Figure 9. The MC-MIO-16 has only eight lines for digital input/output. To minimize the number of lines used for this single operation a multiplexer was installed (Fig. 9). Actuation of terminal 26 low on the I/O

interface provided digital signals from the channel coding lines 1A to 4A as output on terminals 25, 27, 29 and 31 on the I/O interface bus thereby making possible identification of the least significant channel number (i.e., from _0 to _9). Subsequent activation of terminal 26 to a high setting multiplexed the high order channel coding line (1B to 4B) as output to the I/O interface bus which determined the most significant channel number (i.e., from 0_ to 4_). The multiplexer reduced the required number of MC-MIO 16 lines from seven to five.

The second requirement was the control of the Scanivalve® port change mechanism. Connecting terminals five and eight on the back of the Scanivalve® control box actuates the port change mechanism. A relay was wired between these two terminals to give the computer remote control. A pulse generated by the computer and amplified by a gain of two was used to close the relay and thus change ports (Fig. 10).

Finally the voltage output from the pressure transducer must be read by the computer. This output signal was first conditioned by a Pacific Model 8256 amplifier and then read directly by the MC-MIO-16 (Fig. 11). Protection circuitry was not incorporated into the system and so care was taken to ensure that the output of the amplifier did not exceed the limits of the MC-MIO-16 (± 10 V).

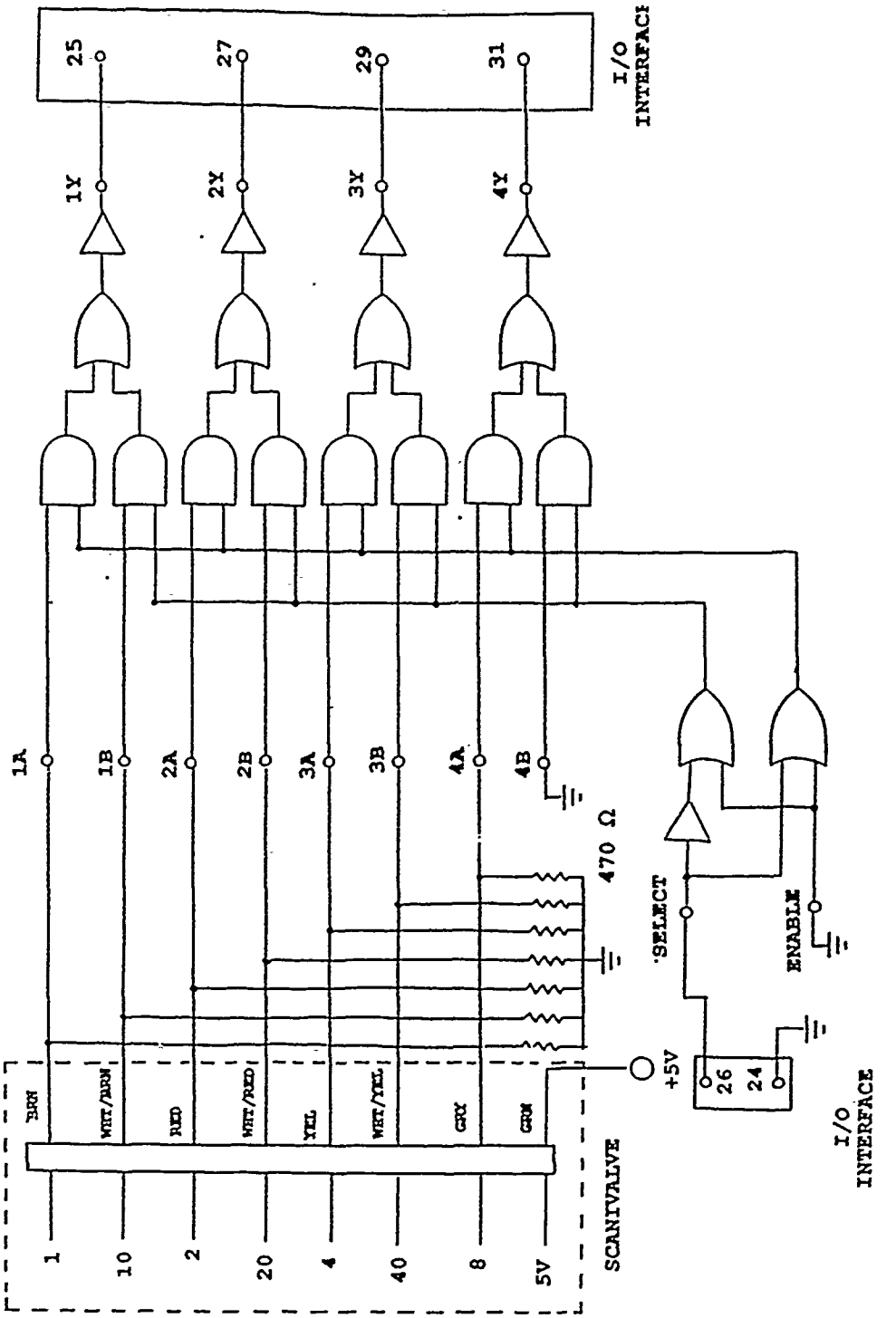

Figure 9. Scanivalve Port Number Acquisition

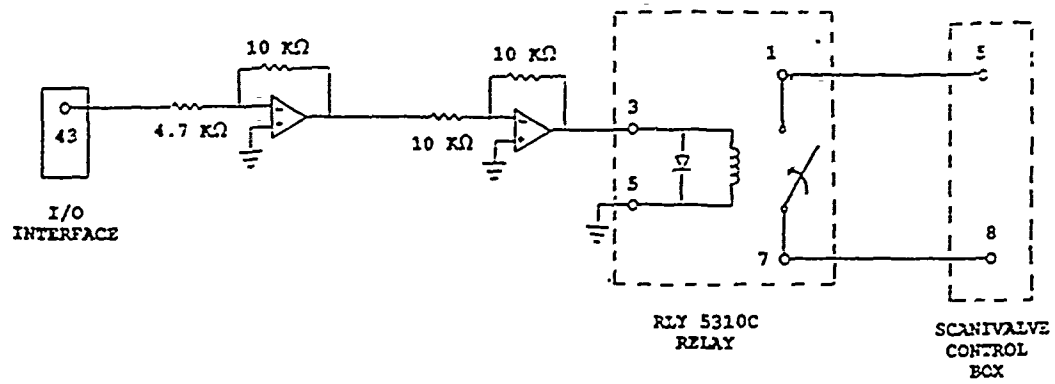

Figure 10. Scanivalve Port Control

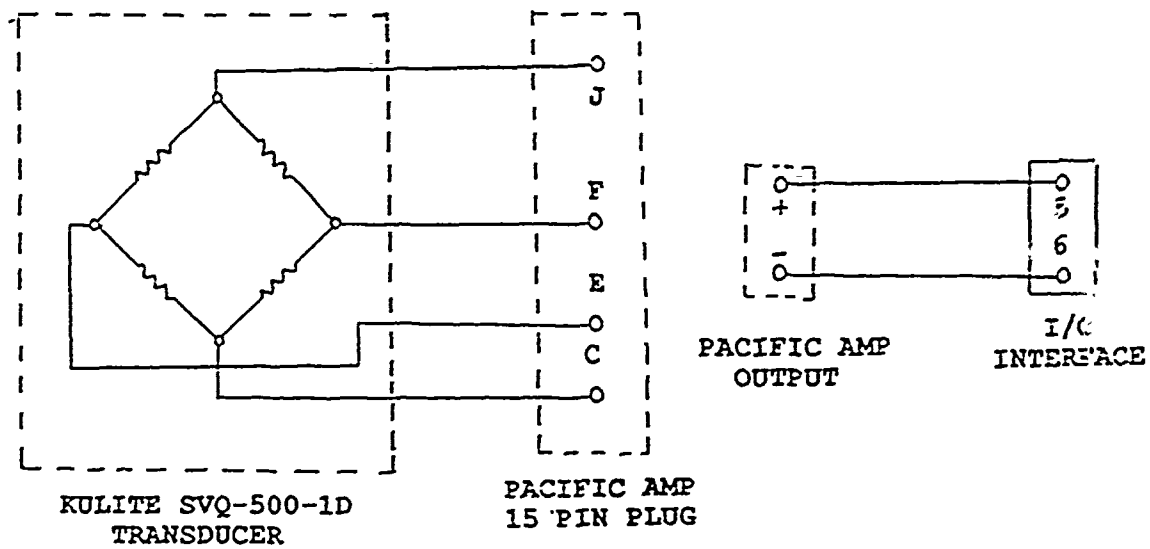

Figure 11. Scanivalve Pressure Acquisition

C. HOT-WIRE

The signal from the linearized hot-wire system was fed through a TSI® Model 157 signal conditioner for gain, offset and low-pass filtering and was then read directly by the MC-MIO-16. No control functions were required.

V. SOFTWARE

To this point all of the hardware required for the wind tunnel calibration has been discussed in detail. Finally, by means of software, the computer may be used to collect the required data and to control the various devices.

A. LABWINDOWS®

LabWindows® is an interactive software program developed by National Instruments. This program allows users to program the many functions of data acquisition without specific knowledge of the procedures for writing to and reading from the various registers. The user selects numerous options on a screen menu while the computer translates these selections into computer code. LabWindows® will program in either QuickBASIC© or C.

While LabWindows® was found to be very helpful in generating code, it was also found to be equally cumbersome for structuring and running the code. Several program flow control commands (e.g., if-then) are not recognized by LabWindows®. The ability to write data to a file during the program run is also not available. For this project LabWindows® was used to write specific data acquisition code and then this code was transferred to QuickBASIC 4.0© for completion of the "flow control" and "data save" requirements. LabWindows®

also contains an analysis library that was called from QuickBASIC© to complete some analysis requirements. The final QuickBASIC© program was compiled and linked to the appropriate LabWindows® libraries and then used as a stand-alone program.

B. AOA AND PRESSURE ACQUISITION

The software required to read and control the angle of attack drive system and the Scanivalve® was written in a menu driven format. The source code is given in the Appendix. The program structure is shown in Figure 12. Each of the subprograms is discussed briefly below.

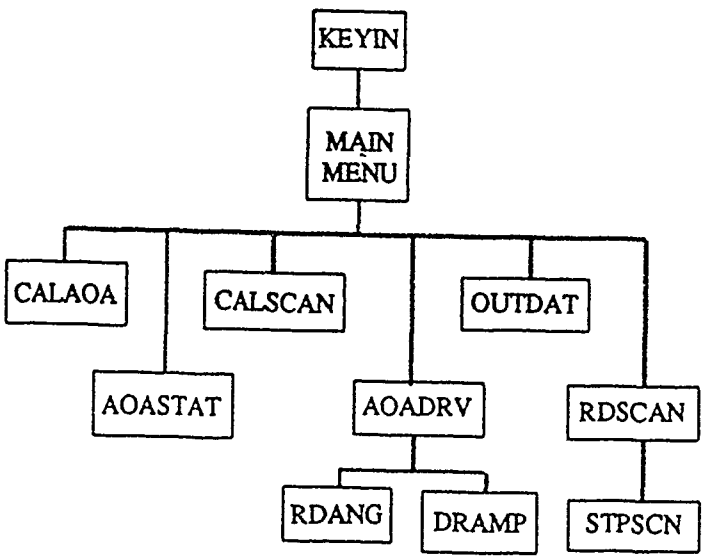

Figure 12. Program Flow Structure

The main program *KEYIN* calls up the menu system and waits for a keyboard input to select a subroutine. Upon completion of the subroutine the program returns to *KEYIN*.

CALAOA was included in the main menu since it would be required to calibrate the angle of attack system. The angle of attack sensor is a gear-driven potentiometer with little variation from day to day. Since the calibration factors did not change this subroutine was disabled. The path and subroutine still exist and can be developed if desired.

AOASTAT was used as an accuracy check on the angle of attack acquisition system. This subroutine returns a mean and standard deviation of the current angle of attack.

AOADRV was initially configured to run with computer and manual control options. The subroutine *DRAMP* provides for computer control. The computer accepts a desired angle of attack input from the keyboard and sends 5 V to the appropriate relay. *RDANG* was intended to provide for an accurate measure of angle of attack while control is maintained manually. This subroutine was not completed; however, the path and file are available if one should wish to implement it.

CALSCAN calibrates the pressure transducer of the Scanivalve®. The subroutine allows the user to zero the amplifier on the atmospheric pressure. The

user is then prompted to input plus and minus 30 cm H_2O on the calibration manometer. The software determines the new slope for pressure versus voltage output. This value is saved as a global variable and so is available in any subroutine. A default value for this slope is loaded on initiation of the program; however, for accuracy this calibration should be performed on a regular basis.

The *RDSCAN* subroutine reads four consecutive pressure ports from the Scanivalve®. The user is prompted to input the first of four ports to read. The program is set up such that the four ports must be consecutive (i.e., 30,31.32,33). Another subroutine, *STPSCN*, is called to set the Scanivalve® to the first port. Each port is read 25 times and an average is taken. The ratio of the dynamic pressures is saved in a file c:\CALDAT while the mean pressures from each port are saved in c:\PDAT.

The subroutine *OUTDAT* was intended to allow the user to direct the data to any desired output (saved files, graphing, printed data, etc). This was found to be a large task not necessary for the current application. Again the path and subroutine are present should a future user decide to develop them.

C. HOT-WIRE

The program *SAMPVOLT* was developed to acquire data at a rate of 20000 samples per second and to store 4096 values in a file for future analysis. The

program saves three sets of data in the files a:\tur20ka.dat. a:\tur20kb.dat, and a:\tur20kc.dat. This data was later analyzed using PC MATLAB©.

VI. RESULTS

A. ANGLE OF ATTACK

The desired accuracy of ± 0.01° was obtained for both the acquisition and control of the angle of attack. An increase in the gain would make the system even more precise. This increase in gain would also reduce the range of angle of attack available. This constraint is due to the ± 10 V limit on the MC-MIO-16. As mentioned earlier the motor speed was reduced to preserve the accuracy requirements. At higher motor speeds the angular momentum would prevent stopping the pitch angle drive mechanism at a value with the stated accuracy goal.

The use of an operational amplifier for gain and offset proved to be too limiting. With the current resistor setup the angle of attack range is limited to ±19°. If, for a given application, the accuracy of .01° was not important but rather a larger range of angle of attack was desired the operational amplifier would have to be reconfigured. Similarly if a model was mounted such that the nose was five degrees low with the tunnel supports level the available angle of attack range would be +14° to -24°. To change the offset in order to return the range to ± 19° would again require a reconfiguration of the operational amplifier. The gain and offset tasks would be performed with much more flexibility if an amplifier with

variable gain and offset were used. One of the four available Pacific amplifiers would serve well for this purpose. In the event an amplifier was used circuitry would be required to protect the computer from the possibility of an excessive gain being applied resulting in outputs above the ± 10 V limit of the MC-MIO-16.

Finally to obtain the desired offset a five volt source was required. Initially the MC-MIO-16 was used to provide this source (pin 34). This source was found to contain too much noise to achieve the desired accuracy. The MC-MIO-16 should not be used as a voltage source if a high degree of accuracy is required.

B. TEST SECTION AIRSPEED DETERMINATION

The data for the airspeed calibration is shown in Figure 13. Each of the points on this curve is the result of an averaging of 25 samples of each of the four pressure signals. The dynamic pressure represented by the x-axis is that at the test section. P_t-P_s is the reference pressure differential measured at the test section inlet. This data exhibits a fairly large amount of scatter. The scatter is believed to be the result of oscillations in total pressure of the tunnel. Ideally the wind tunnel total pressure would be steady and the pressure readings of reference versus calibration sensors would not require sampling at precisely the same time. With unsteady flow and the delay required for a pressure signal to reach the transducer, the ratio of the two signals fluctuates.

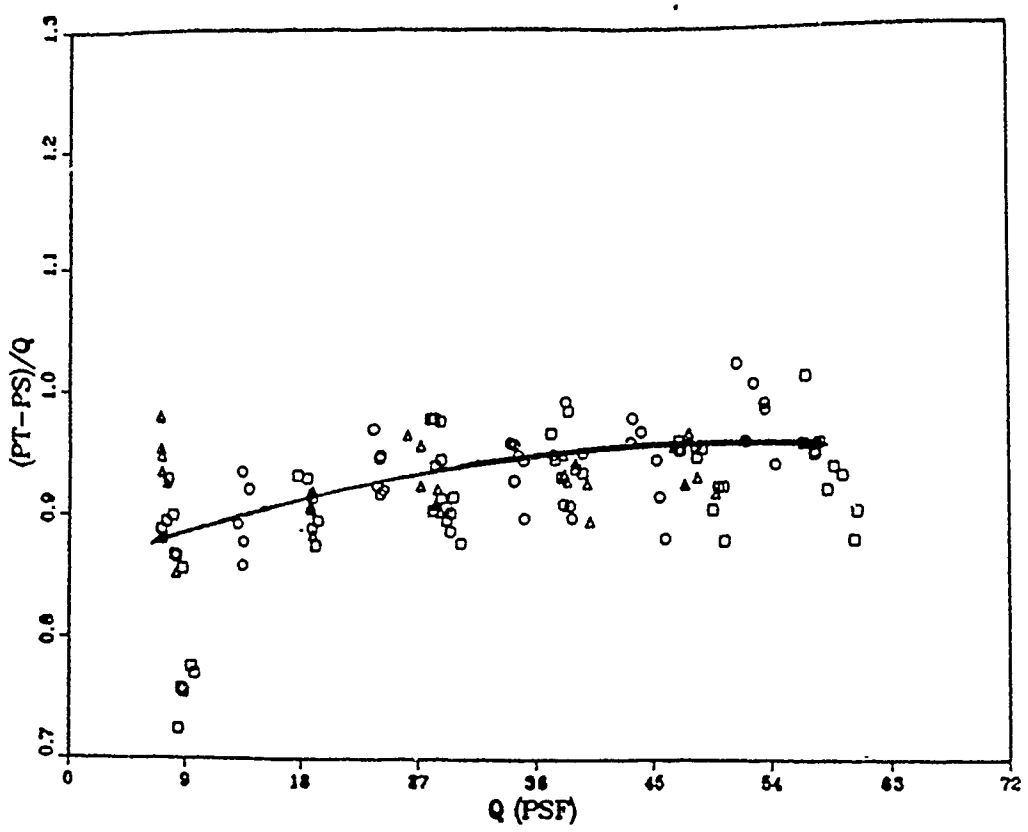

Figure 13. Airspeed Calibration

The cause of the scatter in Figure 13 was investigated in some detail. The purpose of the investigation was to ensure the results were caused by the wind tunnel and not a result of the pressure sensing system. During this process it was determined that the test section doors were leaking and the seals were replaced. It was also found that when a new port was selected on the Scanivalve® the time required for the pressure to stabilize was significant. A delay (approximately 0.5 sec.) was introduced into the software to account for this. Finally when steady,

known pressures were fed to the Scanivalve® from a calibration manometer the signal was read to the accuracy of the MC-MIO-16.

The data shown in Figure 13 was taken after the corrections given above were implemented. It is believed that the scatter shown is a result of the wind tunnel flow characteristics and is not due to inaccuracies in the pressure sensing system.

C. TURBULENCE MEASUREMENTS

The initial results of the turbulence measurements are given in Table I. The values for the turbulence intensity at the two lowest test section dynamic pressures were considered as theoretically beyond reason and were suspected to be the result of some resonant response of the wire or support. The remaining values are also higher than would be expected in a wind tunnel.

To obtain a clearer picture of the turbulence the spectral density was computed. Figure 14 shows the power spectral density of the turbulence obtained by the hot-wire system with the set-up shown in Figure 6 at a test section dynamic pressure of 30 lb/ft^2. The spikes seen in Figure 14 are uncharacteristic of wind tunnel turbulence.

In the development of the equation for the measurement of the turbulence intensity it was assumed that the vertical velocity component was zero. The original hot-wire was mounted to the plywood floor of the tunnel and it was suspected that the vertical vibration of the floor was biasing the turbulence

TABLE I. Turbulence Intensity

$Q_{test\ section}$ (lb/ft-ft)	Turb Int (%)
10	60
15	35
20	2.0
25	2.7
30	2.8
35	2.8
40	2.8
45	2.8
50	3.0
55	3.0

measurement resulting in an excessive vertical velocity component. To eliminate the effects of the floor vibration the hot-wire was mounted to the isolated balance located beneath the test section (see Fig. 15).

In addition to changing the mounts a low-pass filter was installed to eliminate any bias caused by signals above 10000 Hz. The length of a vector was limited to 5000 elements in the language used for the software. This constraint limited the sampling time available. For a frequency of 10000 Hz (20000 Hz sampling frequency) only one quarter of a second of the signal could be observed. In order

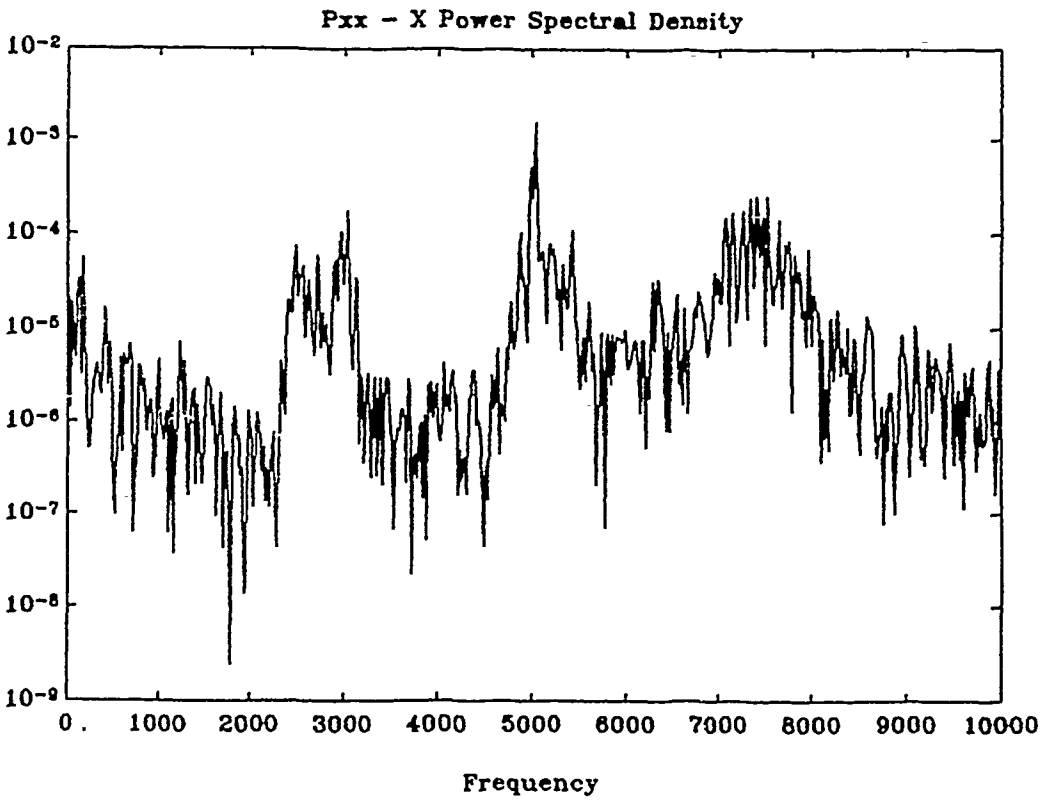

Figure 14. Power Spectral Density Mount One

to maintain at least one quarter second of signal observation the sampling frequency was set at 20000 Hz and so the filter was used. Ideally one would sample at the 91000 Hz rate advertised for the MC-MIO-16.

Figure 16 shows the results with the second mount and the filter installed. The uncharacteristic spikes have been eliminated. A plot was also made with the filter disconnected to ensure the spikes were not purely a result of bias from higher frequency signals that were now being filtered. That plot exhibited a spectral density much like Figure 16.

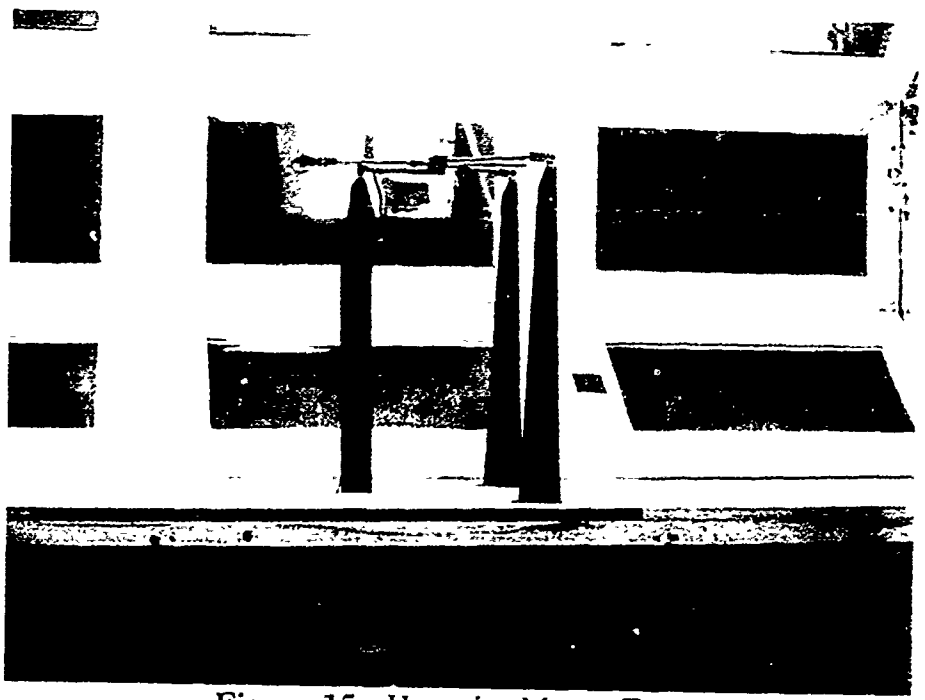

Figure 15. Hot-wire Mount Two

The turbulence intensities for $Q_{test\ section} = 30\ lb/ft^2$ are given in Table II. All values shown include the axial and vertical velocity perturbations. The value for the turbulence due to only the axial velocity perturbations will be less. An assumption of isotropic turbulence decreases these values by a factor of 0.707. The RMS readings were taken from a meter and the value shown is the maximum value observed. The numerical results are expected to be lower than the RMS meter since these results are not the maximum but the level for the 1/4 of a second the signal was observed. This data reinforces the statement above that turbulence was not being filtered out by the low-pass filter. The values given in Table II are a true

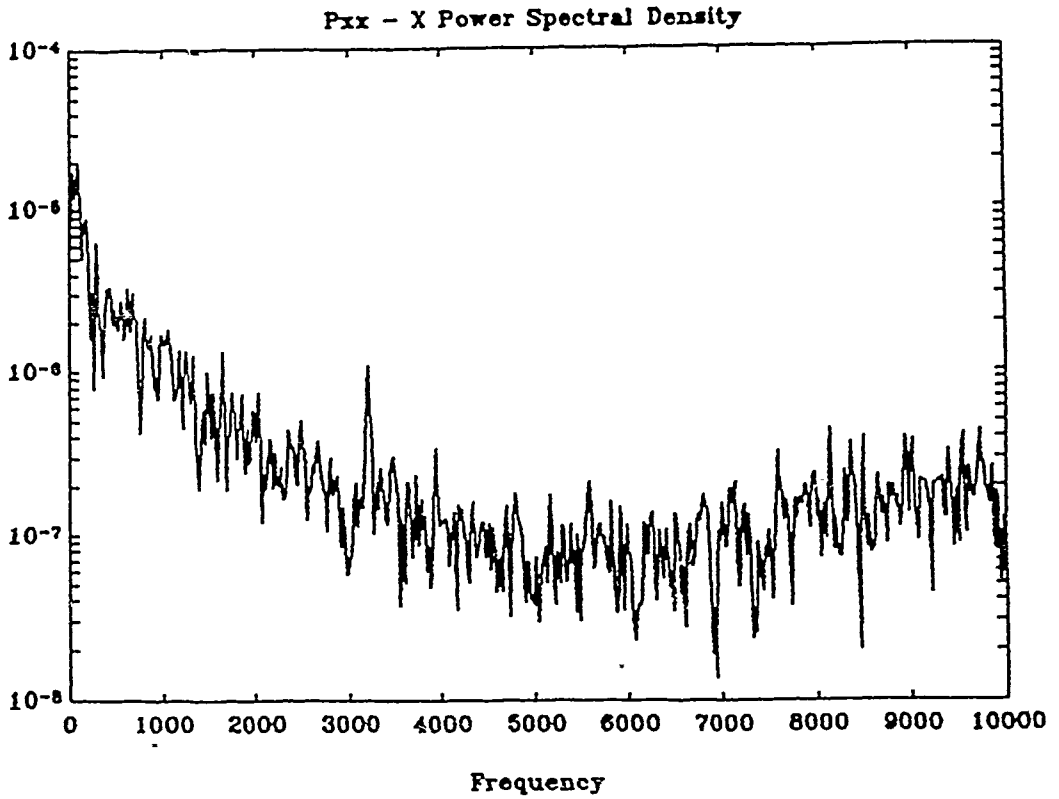

Figure 16. PSD With Mount Two and Low-Pass Filter

representation of the turbulence intensity free of bias from external motion upon the sensor. Finally the axial turbulence length scale was estimated to be 0.2 inches through the application of the Dryden model given in Equation 3.9.

TABLE II. Turbulence Intensity Mount Two

Linear System Mount 2	Numerical Turb Int (%)	RMS Meter (%)
Filtered	.4 .4 .4	.6
Unfiltered	.4 .5 .4	.6

VII. CONCLUSIONS AND RECOMMENDATIONS

The results of this thesis show that even in a degraded co. guration the turbulence level is low enough that screens should reduce it to an acceptable level. Of the five calibration variables listed in Chapter I, two were completed. The longitudinal pressure gradient was shown to be acceptable in past calibrations and should not be affected by the change in operating configuration. The flow angularity and lateral velocity variation have not yet been addressed.

In the present configuration some flow of swirl is expected in the tunnel. Because of previous blade damage the wind tunnel has been reduced to a single rotor tunnel without the stator vanes used to straighten the flow in most single rotor, return flow tunnels. The amount of swirl present still needs to be determined by the procedures outlined in Chapter I. The ideal solution to reducing any swirl would be to rework the damaged blades. This solution would reduce the swirl while adding to the total pressure available. Any remaining swirl could then be eliminated using the tabs on the turning vanes just upstream of the test section. Another method available is to put flow straighteners in the settling chamber. While a viable alternative this method will reduce the total pressure available. Finally the use of stator vanes would be expensive to implement in a tunnel that

has already been designed and constructed and so is not considered an option. In any event this is an area that still needs to be addressed.

The Scanivalve® currently being used on the wind tunnel is in need of rework. With extended use oil leaks into the pressure sensing chamber and contaminates the pressure transducer surface. This problem created several delays during this project.

The delay time required for the pressure to stabilize in the Scanivalve® eliminates the ability for near instantaneous airspeed readings. A pressure transducer dedicated to airspeed determination would allow more instantaneous velocity readings. First the pressure signal could be converted to an electrical signal very close to the tunnel and therefore reduce the time required for the signal to propagate to the computer. Second, and more important, the pressure chamber of the transducer would always be stabilized and the delay written into the computer code could be eliminated. Since this tunnel has a balance system available a Scanivalve® would not be required for all experiments. A dedicated ransducer would allow the Scanivalve® to be used on other experiments.

For the purpose of the airspeed calibration a second transducer would make the measurements more precise. In the present set-up the Scanivalve® references all pressures to atmospheric pressure and so four separate measurements are required. As mentioned above a delay is required between each of these readings

which results in a comparison of the two required pressure differences taken at different times. A second transducer would allow a direct measurement of ΔP and so the two pressure differences could be obtained almost simultaneously.

Finally a barometer source is required to calculate values for the Mach number and the Reynolds number. The previous mercury barometer was removed to comply with Navy safety regulations and has not yet been replaced.

The 3.5' x 5.0' wind tunnel has the potential to become a valuable tool for research by the students of the Department of Aeronautics and Astronautics. The tunnel has a large test section with excellent optical access and has a three component balance available for direct measurement of lift, drag and pitching moment. The results of this thesis show that the turbulence level is not extreme and should be brought to within acceptable levels through the use of screens. The academic staff of the department has the experience to offer any guidance required to complete the restoration of this tunnel. With the required resources this goal can be realized.

APPENDIX COMPUTER CODE

A. KEYIN

```
DECLARE SUB calaoa ()
DECLARE SUB calscan (pressm#)
DECLARE SUB aoastat ()
DECLARE SUB aoadrv ()
DECLARE SUB rdscan (pressm#)
DECLARE SUB mainmenu ()
DECLARE SUB outdat ()
COMMON SHARED pressm#
CLS
pressm# = .082285
CALL mainmenu
DO
   KEY OFF
   FOR J% = 1 TO 10: KEY J%, "": NEXT J%
   DO
      e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
   c = ASC(e$)
   IF c = 59 THEN CALL calaoa
   IF c = 60 THEN CALL calscan(pressm#)
   IF c = 61 THEN CALL aoastat
   IF c = 62 THEN CALL aoadrv
   IF c = 63 THEN CALL rdscan(pressm#)
   IF c = 64 THEN CALL outdat
LOOP UNTIL c = 65
END
```

B. MAINMENU

```
SUB mainmenu STATIC
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
 LOCATE j, 7: PRINT CHR$(186)
 LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 35
PRINT "  MAIN MENU  "
LOCATE 9, 23
PRINT "                                "
LOCATE 10, 23
PRINT "  F1:  Calibrate AOA Sensor          "
LOCATE 11, 23
PRINT "  F2:  Calibrate Scanivalve          "
LOCATE 12, 23
PRINT "  F3:  Check Accuracy of AOA Reading  "
LOCATE 13, 23
PRINT "  F4:  Set AOA                       "
LOCATE 14, 23
PRINT "  F5:  Read Scanivalve               "
LOCATE 15, 23
PRINT "  F6:  Output Data                   "
LOCATE 16, 23
```

```
PRINT "  F7:  Quit                    "
LOCATE 17, 23
PRINT "                               "
' BEEP

END SUB
```

C. CALAOA

```
DECLARE SUB mainmenu ()

SUB calaoa STATIC
'*************************************************************
'
' This subroutine calibrates the AOA read system.  The
' relationship between volts read and AOA is determined
' from manually setting two angles and reading the voltage.
'
'*************************************************************
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
   LOCATE j, 7: PRINT CHR$(186)
   LOCATE j, 74: PRINT CHR$(186)
NEXT j
```

```
LOCATE 6, 32
PRINT "  CALIBRATE AOA  "
LOCATE 11, 30
PRINT "                 "
LOCATE 12, 30
PRINT "  Procedure Disabled  "
LOCATE 13, 30
PRINT "                 "
LOCATE 14, 30
PRINT "  Press F7 To Return  "
LOCATE 15, 30
PRINT "    To Main Menu     "
LOCATE 16, 30
PRINT "                 "
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
      e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
   c = ASC(e$)
LOOP UNTIL c = 65
CALL mainmenu
END SUB
```

D. AOASTAT

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'
DECLARE SUB mainmenu ()

SUB aoastat STATIC
```

```
'*****************************************************************
'
' This subroutine determines the accuracy of the AOA read
' system. It provides a mean and standard deviation at the
' current AOA.
'
'*****************************************************************
t..00001% = Init.DA.Brds(1, t..00000%)
t..00002% = AI.Setup(1, 0, 1)
DIM alpha#(20)
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
   LOCATE j, 7: PRINT CHR$(186)
   LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 29
PRINT "  AOA PEAD STATISTICS  "
LOCATE 10, 23
PRINT "                       "
LOCATE 11, 23
PRINT "  Mean AOA =           "
LOCATE 12, 23
PRINT "  Max AOA =            "
LOCATE 13, 23
```

```
PRINT "  Min AOA =              "
LOCATE 14, 23
PRINT "  Standard Deviation =  "
LOCATE 15, 23
PRINT "                         "
FOR j% = 0 TO 19
   t..00016% = AI.Read(1, 0, 1, angle%)
   t..00018% = AI.Scale(1, 1, angle%, anglev#)
   alpha#(j%) = (anglev# - .65918) / .49034
NEXT j%
CALL Mean(alpha#(), 20, meanval#)
CALL StdDev(alpha#(), 20, meanval#, dev#)
CALL MaxMin(alpha#(), 20, max#, t..00004%, min#, t..00005%)
LOCATE 11, 37
PRINT USING "###.###"; meanval#
LOCATE 11, 44
PRINT "      "
LOCATE 12, 37
PRINT USING "###.###"; max#
LOCATE 12, 44
PRINT "      "
LOCATE 13, 37
PRINT USING "###.###"; min#
LOCATE 13, 44
PRINT "      "
LOCATE 14, 44
PRINT USING "#.####"; dev#
LOCATE 14, 50
PRINT " "
LOCATE 20, 23
PRINT "  Press F7 To Return  "
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
     e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
```

```
   c = ASC(e$)
LOOP UNTIL c = 65
CLS
CALL mainmenu
END SUB
```

E. AOADRV

```
DECLARE SUB dramp ()
DECLARE SUB readang ()
DECLARE SUB mainmenu ()

SUB aoadrv STATIC
'*************************************************************************
'
' This subroutine controls the method used to change the AOA.
' The two options are manual and computer controlled.  In manual
' the computer will give a readout of current AOA.  In computer
' the desired AOA is input in degrees and the computer automatically
' sets the desired AOA.  The speed on the manual box should be set
' at about 40% to eliminate overshoot.
'
'*************************************************************************
DO
   SCREEN 9, 0
   COLOR 14, 3
   LINE (50, 45)-(590, 300), 1, BF
   LOCATE 4, 7
   FOR j = 1 TO 68
      PRINT CHR$(205);
   NEXT j
   LOCATE 22, 7
   FOR j = 1 TO 68
      PRINT CHR$(205);
   NEXT j
   LOCATE 4, 7: PRINT CHR$(201)
   LOCATE 22, 7: PRINT CHR$(200)
   LOCATE 4, 74: PRINT CHR$(187)
```

```
    LOCATE 22, 74: PRINT CHR$(188)
    FOR j = 5 TO 21
       LOCATE j, 7: PRINT CHR$(186)
       LOCATE j, 74: PRINT CHR$(186)
    NEXT j
    LOCATE 6, 35
    PRINT "  SET AOA  "
    LOCATE 9, 23
    PRINT "                          "
    LOCATE 10, 23
    PRINT "  F1: Computer Control     "
    LOCATE 11, 23
    PRINT "  F2: Manual Control       "
    LOCATE 12, 23
    PRINT "  F7: Return To Main Menu  "
    LOCATE 13, 23
    PRINT "                          "
    DO
       KEY OFF
       FOR j% = 1 TO 10: KEY j%, "": NEXT j%
       DO
          e$ = INKEY$
       LOOP UNTIL e$ <> ""
       e$ = RIGHT$(e$, 1)
       c = ASC(e$)
       fromsub% = 0
       IF c = 59 THEN
          CALL dramp
          c = 65
          fromsub% = 1
       END IF
       IF c = 60 THEN
          CALL readang
          c = 65
          fromsub% = 1
       END IF
    LOOP UNTIL c = 65
LOOP WHILE fromsub% = 1
```

```
CLS
CALL mainmenu
END SUB
```

F. DRAMP

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'

SUB dramp STATIC
'*****************************************************************
'
' THIS SUBROUTINE ACCEPTS AN INPUT FOR THE DESIRED ANGLE
(DEG)
' CONVERTS IT TO THE DESIRED OUTPUT , READS THE ACTUAL
' VOLTAGE IN BINARY, CONVERTS THAT TO A VOLTAGE, COMPARES
' THE TWO AND DRIVES THE AOA TO THE DESIRED VALUE.
AVERAGING
' IS USED TO GET THE DESIRED ACCURACY OF .01 DEGREES.
'
' THE VARIABLES USED ARE:
'
'       VOLTI# = INITIAL VOLTAGE (PRIOR TO RUN, AVE)
'       MNALPHI# = INITIAL AOA
'       BINI% = INITIAL BINARY
'       ALPHD# = DESIRED AOA
'       VOLTD# = DESIRED VOLTAGE
'       BINA% = ACTUAL BINARY
'       VOLTA# = ACTUAL VOLTAGE
'       ALPHA# = ACTUAL AOA DURING RUN
'       MNALPHF# = ACTUAL AOA AFTER RUN
'
'*****************************************************************
```

```
'
DIM alphi#(20), alphf#(20)
i..dummy% = Init.DA.Brds(1, t..00000%)
i..dummy% = AI.Setup(1, 0, 1)
i..dummy% = AO.Write(1, 0, 0): REM  ZERO VOLTS TO UP
i..dummy% = AO.Write(1, 1, 0): REM  ZERO VOLTS TO DOWN
'
'  INITIAL AOA
'
CLS
FOR j% = 0 TO 19
    i..dummy% = AI.Read(1, 0, 1, bini%)
    i..dummy% = AI.Scale(1, 1, bini%, volti#)
    alphi#(j%) = (volti# - .65918) / .49034
NEXT j%
CALL Mean(aiphi#(), 20, mnalphi#)
PRINT "AOA IS NOW";
PRINT USING "###.###"; mnalphi#
'
'   INPUT
'
10 j% = 1
WHILE j% = 1
j% = 0
INPUT "INPUT DESIRED AOA IN DEG (90 to return to last menu)"; alphd#
IF alphd# = 90# THEN
     GOTO 100
END IF
IF (alphd# < -19#) OR (alphd# > 19#) THEN
   PRINT "AOA OUT OF LIMITS. INPUT VALUE BETWEEN -19 AND 19."
   j% = 1
END IF
voltd# = .49034 * alphd# + .65918
WEND
'
'  A-TO-D OF ACTUAL ANGLE
'
i..dummy% = AI.Read(1, 0, 1, bina%)
```

```
i..dummy% = AI.Scale(1, 1, bina%, volta#)
alpha# = (volta# - .65918) / .49034
'
' D-TO-A DRIVE MOTOR
'
'
WHILE alpha# < alphd#
      i..dummy% = AO.VScale(1, 0, 5!, five%)
      i..dummy% = AO.Write(1, 1, 0): REM  ZERO VOLTS TO DOWN
      i..dummy% = AO.Write(1, 0, five%): REM  5 VOLTS TO UP
      i..dummy% = AI.Read(1, 0, 1, bina%)
      i..dummy% = AI.Scale(1, 1, bina%, volta#)
      alpha# = (volta# - .65918) / .49034
WEND
WHILE alpha# > alphd#
      i..dummy% = AO.VScale(1, 0, 5!, five%)
      i..dummy% = AO.Write(1, 0, 0): REM  ZERO VOLTS TO UP
      i..dummy% = AO.Write(1, 1, five%): REM  FIVE VOLTS TO DOWN
      i..dummy% = AI.Read(1, 0, 1, bina%)
      i..dummy% = AI.Scale(1, 1, bina%, volta#)
      alpha# = (volta# - .65918) / .49034
WEND
'
' STOP MOTOR
'
i..dummy% = AO.Write(1, 0, 0): REM  ZERO VOLTS TO UP
i..dummy% = AO.Write(1, 1, 0): REM  ZERO VOLTS TO DOWN
'
' READ FINAL AOA
'
FOR k% = 0 TO 1000
NEXT k%
FOR j% = 0 TO 19
  i..dummy% = AI.Read(1, 0, 1, binf%)
  i..dummy% = AI.Scale(1, 1, binf%, voltf#)
  alphf#(j%) = (voltf# - .65918) / .49034
NEXT j%
CALL Mean(alphf#(), 20, mnalphf#)
```

```
PRINT "AOA = ";
PRINT USING "###.###"; mnalphf#
GOTO 10
100 CLS
END SUB
```

G. RDANG

```
SUB readang STATIC
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
 LOCATE j, 7: PRINT CHR$(186)
 LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 29
PRINT "  MANUAL AOA CONTROL  "
LOCATE 11, 30
PRINT "                      "
LOCATE 12, 30
PRINT "  Procedure Disabled  "
LOCATE 13, 30
PRINT "                      "
LOCATE 14, 30
PRINT "  Press F7 To Return  "
```

```
LOCATE 15, 30
PRINT "    To Main Menu      "
LOCATE 16, 30
PRINT "                      "
' BEEP
DO
KEY OFF
FOR j% = 1 TO 10: KEY j%, ""; NEXT j%
DO
e$ = INKEY$
LOOP UNTIL e$ <> ""
e$ = RIGHT$(e$, 1)
c = ASC(e$)
LOOP UNTIL c = 65
END SUB
```

H. CALSCAN

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'
DECLARE SUB mainmenu ()

SUB calscan (pressm#) STATIC
'*************************************************************************
'
' This subroutine calibrates the transducer in the scanivalve.
' The variable pressm# is a global variable and carries the
' value of the relationship between volts read and psi.  If this
' subroutine is skipped the value for pressm# is the default
' found in the module keyin.
'
'*************************************************************************
t..00001% = Init.DA.Brds(1, t..00000%)
```

```
t..00002% = DIG.Prt.Config(1, 0, 0, 0)
t..00002% = DIG.Prt.Config(1, 1, 0, 1)
t..00002% = AI.Setup(1, 1, 1)
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
   PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
   LOCATE j, 7: PRINT CHR$(186)
   LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 29
PRINT "  CALIBRATE SCANIVALVE       "
LOCATE 11, 30
PRINT "                             "
LOCATE 12, 30
PRINT "  F1:   Continue             "
LOCATE 13, 30
PRINT "                             "
LOCATE 14, 30
PRINT "  F7:   Main menu            "
LOCATE 15, 30
PRINT "                             "
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
```

```
      e$ = INKEY$
    LOOP UNTIL e$ <> ""
    e$ = RIGHT$(e$, 1)
    c = ASC(e$)
    IF c = 65 THEN
      CLS
      GOTO 1000
    END IF
LOOP UNTIL c = 59
CLS
PRINT "Input port number to zero amp (port open to atmosphere)"
INPUT p%
CALL stpscn(p%)
c = 0
CLS
DO
    KEY OFF
    FOR j% = 1 TO 10: KEY j%, "": NEXT j%
    DO
      LOCATE 6, 29
      PRINT "Adjust 'zero in' screw on amp until zero"
      LOCATE 7, 29
      PRINT "Press any key after zeroed"
      FOR k# = 1 TO 3000 STEP .5
      NEXT k#
      CLS
      t..00003% = AI.Read(1, 1, 1, presb%)
      t..00004% = AI.Scale(1, 1, presb%, presv#)
      LOCATE 9, 29
      PRINT USING "#.####"; presv#
      e$ = INKEY$
    LOOP UNTIL e$ <> ""
    e$ = RIGHT$(e$, 1)
    c = ASC(e$)
LOOP UNTIL c <> 0
CLS
INPUT "Input calibration port number"; p%
CALL stpscn(p%)
```

```
CLS
PRINT "Set 30 cm on calibration manometer (left side high)"
PRINT "Press F1 to continue"
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
     e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
   c = ASC(e$)
LOOP UNTIL c = 59
prest# = 0#
FOR i% = 1 TO 50
   t..00003% = AI.Read(1, 1, 1, presb%)
   t..00004% = AI.Scale(1, 1, presb%, presv#)
   prest# = prest# + presv#
NEXT i%
volt# = prest# / 50
PRINT "volts ="; volt#
PRINT "Set -30 cm on calibration manometer (right side high)"
PRINT "Press F1 to continue"
c = 0
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
     e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
   c = ASC(e$)
LOOP UNTIL c = 59
prest# = 0#
FOR i% = 1 TO 50
   t..00003% = AI.Read(1, 1, 1, presb%)
   t..00004% = AI.Scale(1, 1, presb%, presv#)
   prest# = prest# + presv#
NEXT i%
```

```
voltm# = prest# / 50
pressm# = .85243 / (volt# - voltm#)
CLS
PRINT "volt ="; voltm#
PRINT "Calibration complete"
PRINT "Slope (psi/volt) ="; pressm#
PRINT "Press F7 to return to main menu"
DO
   KEY OFF
   FOR j% = 1 TO 10: KEY j%, "": NEXT j%
   DO
     e$ = INKEY$
   LOOP UNTIL e$ <> ""
   e$ = RIGHT$(e$, 1)
   c = ASC(e$)
LOOP UNTIL c = 65
CLS
1000 CALL mainmenu
END SUB
```

I. RDSCAN

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'
DECLARE SUB mainmenu ()

SUB RDSCAN (pressm#) STATIC
i..dummy% = Init.DA.Brds(1, t..00000%)
i..dummy% = DIG.Prt.Config(1, 0, 0, 0)
i..dummy% = DIG.Prt.Config(1, 1, 0, 1)
i..dummy% = AI.Setup(1, 1, 1)
DIM psinl#(25), ptinl#(25), pstst#(25), pttst#(25)
dec% = 1
```

```
OPEN "c:caldat" FOR OUTPUT AS #1
OPEN "c:pdat" FOR OUTPUT AS #2
SCREEN 9, 0
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
 LOCATE j, 7: PRINT CHR$(186)
 LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 31
PRINT "  READ SCANIVALVE  "
LOCATE 11, 16
PRINT "                                          "
LOCATE 12, 16
PRINT "  This module is set to read Ps and Pt at        "
LOCATE 13, 16
PRINT "  the test section and the inlet.  The values    "
LOCATE 14, 16
PRINT "  are written to c:\caldat.                      "
LOCATE 15, 16
PRINT "                                          "
LOCATE 16, 16
PRINT "  F1:  Continue          F7:  Main menu         "
LOCATE 17, 16
PRINT "                                          "
DO
```

```
    KEY OFF
    FOR j% = 1 TO 10: KEY j%, "": NEXT j%
    DO
      e$ = INKEY$
    LOOP UNTIL e$ <> ""
    e$ = RIGHT$(e$, 1)
    c = ASC(e$)
    IF c = 65 THEN
      CLS
      GOTO 2000
    END IF
LOOP UNTIL c = 59
CLS
INPUT "Input first of four ports to read (30)"; po%
DO
    p% = po%
    CALL stpscn(p%)
    CLS
    FOR j# = 1 TO 4500 STEP .5
    NEXT j#
    FOR k% = 0 TO 24
      i..dummy% = AI.Read(1, 1, 1, presb%)
      i..dummy% = AI.Scale(1, 1, presb%, presv#)
      psinl#(k%) = pressm# * presv#
    NEXT k%
    CALL Mean(psinl#(), 25, mean1#)
    CALL StdDev(psinl#(), 25, mean1#, dev1#)
    i..dummy% = CTR.Pulse(1, 1, 2, 3, 50)
    FOR j# = 1 TO 4500 STEP .5
    NEXT j#
    FOR k% = 0 TO 24
      i..dummy% = AI.Read(1, 1, 1, presb%)
      i..dummy% = AI.Scale(1, 1, presb%, presv#)
      ptinl#(k%) = pressm# * presv#
    NEXT k%
    CALL Mean(ptinl#(), 25, mean2#)
    CALL StdDev(ptinl#(), 25, mean2#, dev2#)
    i..dummy% = CTR.Pulse(1, 1, 2, 3, 50)
```

```
    FOR j# = 1 TO 4500 STEP .5
    NEXT j#
    FOR k% = 0 TO 24
      i..dummy% = AI.Read(1, 1, 1, presb%)
      i..dummy% = AI.Scale(1, 1, presb%, presv#)
      pstst#(k%) = pressm# * presv#
    NEXT k%
    CALL Mean(pstst#(), 25, mean3#)
    CALL StdDev(pstst#(), 25, mean3#, dev3#)
    i..dummy% = CTR.Pulse(1, 1, 2, 3, 50)
    FOR j# = 1 TO 4500 STEP .5
    NEXT j#
    FOR k% = 0 TO 24
      i..dummy% = AI.Read(1, 1, 1, presb%)
      i..dummy% = AI.Scale(1, 1, presb%, presv#)
      pttst#(k%) = pressm# * presv#
    NEXT k%
    CALL Mean(pttst#(), 25, mean4#)
    CALL StdDev(pttst#(), 25, mean4#, dev4#)
    v# = (2 * 144 * (mean4# - mean3#) / .002376) ^ .5
    msqr# = (v# / 1117) ^ 2
    den# = 1 + msqr# / 4 + msqr# ^ 2 / 40 + msqr# ^ 3 / 1600
    q# = 144 * (mean4# - mean3#) / den#
    r# = 144 * (mean2# - mean1#) / q#
    PRINT USING "##.#####"; q#; r#
    WRITE #1, q#, r#
    WRITE #2, mean1#, mean2#, mean3#, mean4#
'   WRITE #2, dev1#, dev2#, dev3#, dev4#
    INPUT "Input 0 to start another round, 1 to quit"; dec%
LOOP WHILE dec% = 0
CLOSE
CLS
2000 CALL mainmenu
END SUB
```

J. STPSCN

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'

SUB stpscn (p%) STATIC
   i..dummy% = Init.DA.Brds(1, t..00000%)
   i..dummy% = DIG.Prt.Config(1, 0, 0, 0)
   i..dummy% = DIG.Prt.Config(1, 1, 0, 1)
   i..dummy% = DIG.Out.Line(1, 1, 0, 0)
   i..dummy% = DIG.In.Port(1, 0, lowb%)
   t..00004% = DIG.Out.Line(1, 1, 0, 1)
   i..dummy% = DIG.In.Port(1, 0, highb%)
   port% = 10 * highb% + lowb%
WHILE port% <> p%
   FOR i# = 1 TO 2750 STEP .5
   NEXT i#
   i..dummy% = CTR.Pulse(1, 1, 2, 3, 50)
   i..dummy% = DIG.Out.Line(1, 1, 0, 0)
   i..dummy% = DIG.In.Port(1, 0, lowb%)
   t..00004% = DIG.Out.Line(1, 1, 0, 1)
   i..dummy% = DIG.In.Port(1, 0, highb%)
   port% = 10 * highb% + lowb%
   PRINT "port  "; port%
WEND
END SUB
```

K. OUTDAT

```
DECLARE SUB mainmenu ()

SUB outdat STATIC
SCREEN 9, 0
```

```
COLOR 14, 3
LINE (50, 45)-(590, 300), 1, BF
LOCATE 4, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 22, 7
FOR j = 1 TO 68
  PRINT CHR$(205);
NEXT j
LOCATE 4, 7: PRINT CHR$(201)
LOCATE 22, 7: PRINT CHR$(200)
LOCATE 4, 74: PRINT CHR$(187)
LOCATE 22, 74: PRINT CHR$(188)
FOR j = 5 TO 21
 LOCATE j, 7: PRINT CHR$(186)
 LOCATE j, 74: PRINT CHR$(186)
NEXT j
LOCATE 6, 33
PRINT "  OUTPUT DATA  "
LOCATE 11, 30
PRINT "                    "
LOCATE 12, 30
PRINT "  Procedure Disabled  "
LOCATE 13, 30
PRINT "                    "
LOCATE 14, 30
PRINT "  Press F7 To Return  "
LOCATE 15, 30
PRINT "    To Main Menu      "
LOCATE 16, 30
PRINT "                    "
' BEEP
DO
KEY OFF
FOR j% = 1 TO 10: KEY j%, "": NEXT j%
DO
e$ = INKEY$
```

```
LOOP UNTIL e$ <> ""
e$ = RIGHT$(e$, 1)
c = ASC(e$)
LOOP UNTIL c = 65
CALL mainmenu
END SUB
```

L. SAMPVOLT

```
REM     $INCLUDE: 'C:\LW\INCLUDE\LWSYSTEM.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GPIB.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\FORMATIO.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\GRAPHICS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\ANALYSIS.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\DATAACQ.INC'
REM     $INCLUDE: 'C:\LW\INCLUDE\RS232.INC'
i..dummy% = DAQ.Config(1, 0, 0)
DIM bin%(4095)
DIM turb#(4095)
 ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' 100 Hz (4,10); 500Hz (3,20); 1000Hz (3,10); 2000Hz (2,50)      '
' 5000Hz (2,20); 10000Hz (2,10); 20000Hz (1,50); 25kHz (1,40)   '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'' junk
    OPEN "a:junk.dat" FOR OUTPUT AS #9
    t..00007% = DAQ.Start(1, 2, 1, bin%(), 4096, 1, 50)
    PRINT "Sample 1 complete. Saving data."
    FOR k% = 0 TO 4095 STEP 1
    i..dummy% = AI.Scale(1, 1, bin%(k%), turb#(k%))
    WRITE #9, turb#(k%)
    NEXT k%
    CLOSE #9
    t..00000% = DAQ.Clear(1)
'' A
    OPEN "a:tur20ka.dat" FOR OUTPUT AS #2
    t..00007% = DAQ.Start(1, 2, 1, bin%(), 4096, 1, 50)
    PRINT "Sample 2 complete. Saving data."
    FOR k% = 0 TO 4095 STEP 1
```

```
        i..dummy% = AI.Scale(1, 1, bin%(k%), turb#(k%))
        WRITE #2, turb#(k%)
        NEXT k%
        CLOSE #2
        t..00000% = DAQ.Clear(1)
'' B
        OPEN "a:tur20kb.dat" FOR OUTPUT AS #1
        t..00007% = DAQ.Start(1, 2, 1, bin%(), 4096, 1, 50)
        PRINT "Sample 3 complete. Saving data."
        FOR k% = 0 TO 4095 STEP 1
        i..dummy% = AI.Scale(1, 1, bin%(k%), turb#(k%))
        WRITE #1, turb#(k%)
        NEXT k%
        CLOSE #1
        t..00000% = DAQ.Clear(1)
'' C
        OPEN "a:tur20kc.dat" FOR OUTPUT AS #3
        t..00007% = DAQ.Start(1, 2, 1, bin%(), 4096, 1, 50)
        PRINT "Sample 4 complete. Saving data."
        FOR k% = 0 TO 4095 STEP 1
        i..dummy% = AI.Scale(1, 1, bin%(k%), turb#(k%))
        WRITE #3, turb#(k%)
        NEXT k%
        CLOSE #3
        t..00000% = DAQ.Clear(1)
END
```

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